

3D printer modification for printing of HEMA hydrogel

J. Zavřel^a, M. Michalák^a, T. Vampola^a

^a Faculty of Mechanical Engineering, Czech Technical University in Prague, Technická 4, 166 07 Praha, Czech Republic

Hydrogels are widely used materials. We can meet them in products wherever there is a need to absorb liquids. Contact lenses are also made of hydrogel as it is a well biocompatible material [3]. Tissue cell population experiments are also conducted with this material. However, cell growth is dependent on the underlying object's geometry. Because the objects are very diverse in shape, 3D printing can be used to create them.

Hydrogel, based on HEMA, is composed of three basic ingredients. The basic component is HEMA (2-hydroxyethyl methacrylate), followed by crosslinker (about 0,5 % of ethylen dimetacrylate - EDMA) and initiator (activator) in appropriate proportions. Other ingredients, such as water, can be added to obtain different properties of the hydrogel. If water is added, it affects the swelling ability. A very important part is the initiator, which starts crosslinking. The initiator may initiate crosslinking based on mechanical pressure, temperature, UV radiation or other conditions. Depending on the amount of initiator and crosslinker, an appropriate crosslinking rate can be achieved. The speed of crosslinking parameter is an essential for successful printing of the hydrogel.

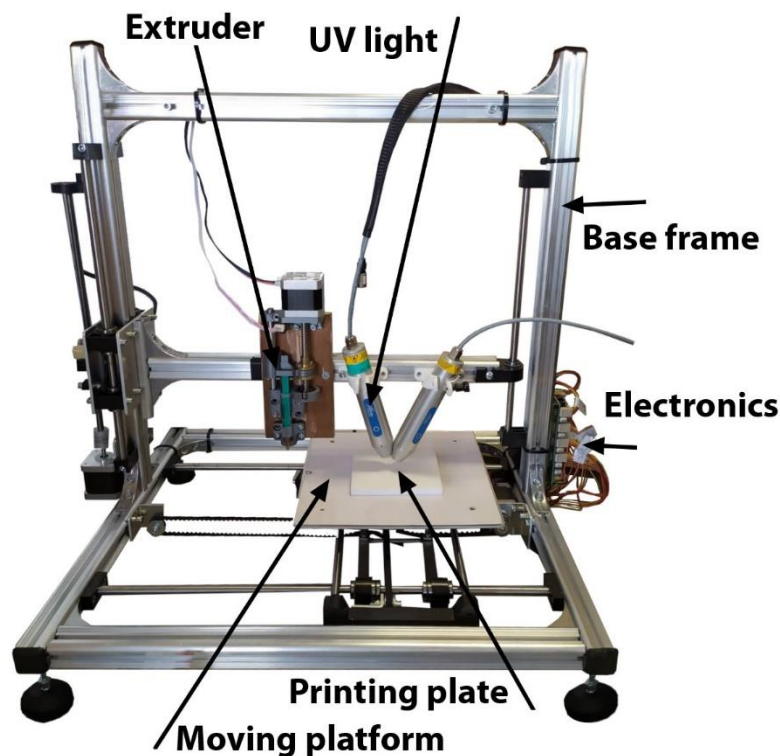


Fig. 1. Modified printer Velleman K8200

After crosslinking, the resulting polymer is blended as an anhydrous, solid, and relatively hard polymer. If water is also added to the mixture, the crosslinking properties are then affected. Such a polymer is then softer and it seems like an already swollen hydrogel. Depending on the composition of the hydrogel, the polymer is then able to absorb from 10 % to 600 % water relative to the dry weight. These properties are crucial to successful 3D printing.

Various methods of 3D hydrogel printing can be encountered [1]. The most common method is to extrude the hydrogel through a nozzle, often to the support material. Depending on the nozzle size, model details can be obtained. Depending on the method of initiating crosslinking, a printing method is also selected. Most often, crosslinking occurs after exposure of the hydrogel to UV radiation. Typically it is used a wavelength from 200 nm to 405 nm. The exposure time of the hydrogel is from a few seconds to several tens of seconds. It also depends on the thickness of the layer to be crosslinked. Another method is based on freezing the hydrogel during printing [2]. It is printed on a sheet of steel sheet. Dry ice is placed under the pad, keeping the steel pad at very low temperatures. Subsequently, the gel is applied to a cooled plate using a needle extruder. The high water content of the gel causes immediate freezing. When printing complex structures, a small amount of water is added to support the printing structure. Upon completion, the object thaws gradually until the ice is thawed and leaves only printed structure from the hydrogel. The last type is a method of applying a hydrogel similar to an inkjet printhead, as is the case with an office printer. This last method is suitable for small and detailed objects.

The design of the 3D hydrogel printer is based on the Velleman K8200 (Fig. 1). This printer is equipped with three feeds in the X, Y and Z axes and an extruder drive. The printer software is based on Marlin firmware. Since the design was not sufficient for printing the hydrogel, a hardware modification was necessary. A major change was the replacement of the filament extruder with other construction of the extruder. Due to the addition of the UV light source and the need to switch it on, it was also necessary to change the firmware and modify it. The printer operates via the Repetier-Host. For the initial tests, this application was sufficient, but with the gradual addition of functionality the work was lengthy. For this reason, MATLAB's control software was created, including preview and online modification of the generated G-code (Fig. 2).

A classic thin-needle syringe is used for the hydrogel extrusion. After it has been filled with hydrogel, the volume of the hydrogel is inserted into the control software and the extruder is brought into the correct position to allow its insertion. The printing of the hydrogel is based on the extrusion of droplets, which are subsequently cured by UV light. The printed object model is based on the solid model, which is exported to STL format using the Slic3r software. Since the printing is based on droplets, the G-code from the slicer must be modified. For these modifications of the G-code, the converting software "přechroupátor" is created. This software is written in MATLAB and modifies the G-code of lines, arcs, and other entities into the same objects from droplets. The software can adjust droplet sizes, retracting and spacing to fine tune print quality.

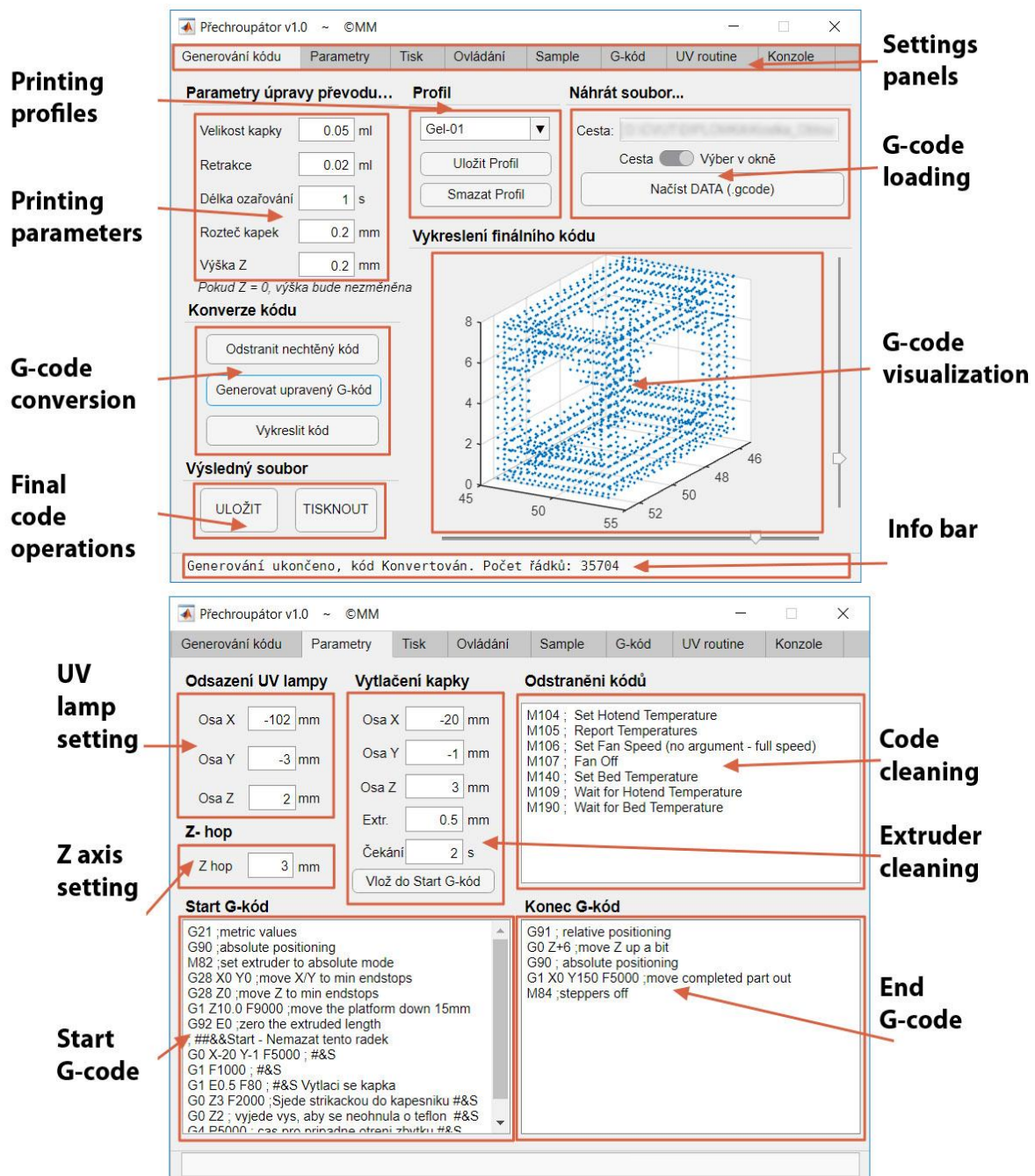


Fig. 2. The print control environment

Replacing a line with an object of droplets (Fig. 3) is based on the slope of the line k and the even distribution of the droplets along the trajectory

$$y = k \cdot x \Rightarrow k = \frac{y}{x}, \quad \text{and after substituting} \quad k = \frac{Y_{\text{Curr}} - Y_{\text{Last}}}{X_{\text{Curr}} - X_{\text{Last}}}$$

The droplet pitch r is then given by the number n of droplets, from which the increment in the X axis can be calculated

$$r^2 = X_{\text{Incr}}^2 + X_{\text{Incr}}^2 \cdot k^2 \Rightarrow X_{\text{Incr}} = \sqrt{\frac{r^2}{1+k^2}}$$

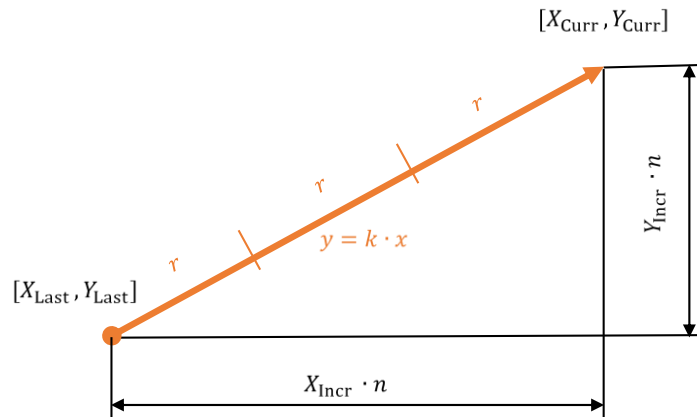


Fig. 3. Replacing a straight line with droplets

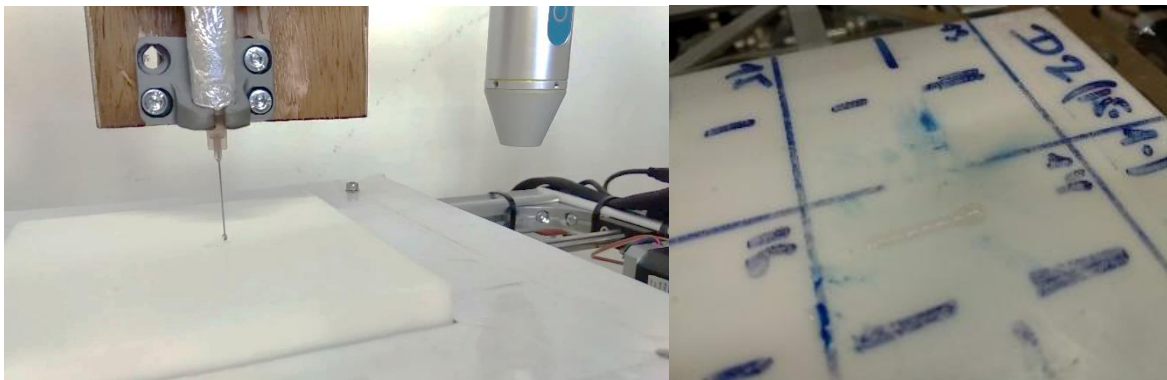


Fig. 4. Printing the droplet at the end of the needle (left) and demonstrating the printing of the line from the droplets (right)

A simple object was chosen to test the functionality of the hydrogel printer. Fig. 4 shows the droplet formation at the end of the needle as well as the printed line. This type of printer is suitable for printing larger objects that do not require high printing accuracy. The resolution is dependent on the size of the droplet and thus the inner diameter of the needle. However, this dimension is closely related to the need to accurately meter the amount of extruded hydrogel that limits the use for detail printing.

Acknowledgements

The research is supported by the Grant Agency of the Czech Republic by project No GA17-08531S – “Computational design of hydrogel cell scaffolds”.

References

- [1] Bittner, S.M., Guo, J.L., Melchiorri, A., Mikos, A.G., Three-dimensional printing of multilayered tissue engineering scaffolds, *Materials Today* 21 (8) (2018) 861-874.
- [2] Tan, Z., Parisi, C., Di Silvio, L., Dini, D., Forte A.L., Cryogenic 3D printing of super soft hydrogels, *Scientific Reports* [online] 7(1) (2017).
- [3] Wichterle, O., Lím, D., Hydrophilic gels for biological use, *Nature* 185 (4706) (1960) 117-118.